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Experimental Study of Heat Dissipation in Indoor Sports Shoes

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Abstract

As indoor sports shoes are intensively used in a warm and sweaty environment for periods of up to three consecutive hours, the built-up heat inside is insufficiently released causing warm and perspiring feet. This results in an increased chance of blisters and skin irritations. Experimental research on the ventilation properties of the shoe was done using a controlled heat source, digital thermometer and thermo-graphic camera. A representative set of five volley- and handball shoes were subjected to performance testing to explore possibilities for improvement. This paper will explain the test set-up, present the experiments results, discuss the outcome from the research experiments and present a set of conclusions and recommendations for further developments in footwear ventilation.

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Keywords: Ventilation; Indoor Sports Shoes; Heat Reduction; Volleyball; Handball; Foot Temperature; Heat Imaging; Heat Sensors

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1. Introduction

The properties of indoor sport shoes are constantly being improved, e.g. durability, grip, traction, stability, comfort, etc. Recently, more attention has been given to the amount of heat a shoe can dissipate. During an average (90 min.) indoor training session in handball or volleyball, the shoes can become very warm and sweaty. Preliminary temperature measurements show temperatures of over 35°C. These in-shoe conditions increase bacteria growth causing fungal infections and foot odour. Additionally, the moist environment can cause increased friction between the skin and shoe, which results in blisters and chafing (Sulzberger et al., 1966). The demand for ventilation or heat dissipation is contradictory to demands like support and performance of the shoe. The objective of this research project is to identify differences in heat dissipation. Next it will be the basis for the development of a solution to increase heat dissipation as well as maintain current levels of performance and support. In order to compare and quantify the heat dissipation of the shoe a controlled heat source was introduced to measure static heat dissipation. Heat Dissipation takes place in the form of conduction, radiation and convection (Moran et al., 2010). Thermoregulation of footwear has been investigated earlier by other authors (Covill et al., 2011) using thermodynamic simulation models. However in this research project, the use of empirical results was chosen over the use of thermodynamic models.

2. Experimental test set-up

2.1. Test objects

Five different shoe models (from three different brands) were subject of research: four top-range models and one low-range model (Table 1). The shoes were selected on their diverging appearances or marketing communication on temperature regulation, e.g. extra light and thin mesh, rubber printed exterior patterns for support or a semi-open plastic/rubber heel shock-absorption system for extra air flow.

Table 1. Overview of shoes used in the experiment.

Shoe Nr.	Brand	Model	Recommended sport by supplier	Recommended retail price	Targeted market segment
1	A	1	Volleyball	€ 150*	Top range
2	A	2	Handball	€ 150*	Top range
3	A	3	Volleyball/Handball	€ 75**	Low range
4	B	1	Volleyball/Handball	€ 130**	Top range
5	C	1	Volleyball	€ 140**	Top range

*Shoes were not yet released onto the market at the time but were released summer 2013 at this recommended retail price according to brand websites.
**Recommended retail price according to brand websites (December 2012).

2.2. Test set-up

The shoe was suspended with only the tip and the end of the outer sole supported (see fig. 1b). This suspension is necessary to enable the shoe to dissipate its heat from all directions. A thin plastic liner is fitted inside the shoe. Boiling water (750 ml from a domestic water cooker) was transferred into a measuring jug where the water was left to cool to 94.0 ± 0.1 ºC and was then poured into the liner inside the shoe. A domestic digital thermometer was calibrated and used to measure temperature.

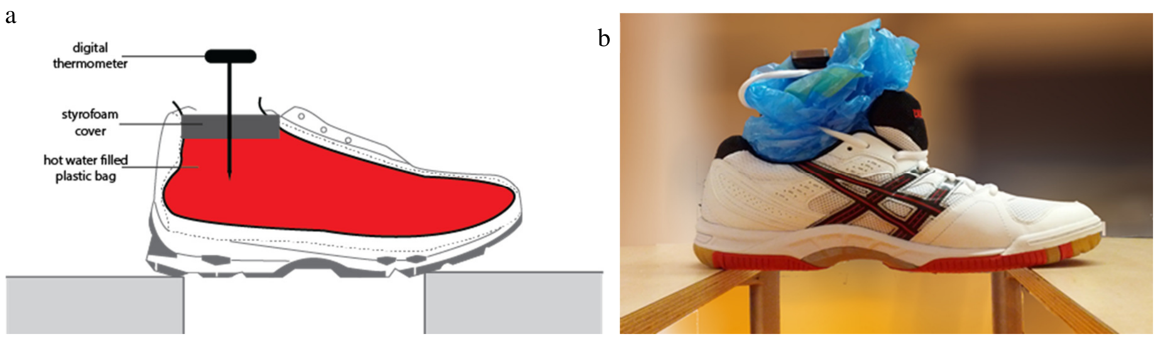

Figure 1. (a) Side view of test set up (b) picture of test set up

The shoe was closed at the top with an oval Styrofoam (PS foam) cover with a thickness of 20 mm. The digital thermometer was suspended in the water in the middle between the top of the innersole and the bottom of the Styrofoam cover. Time was recorded from the moment the Styrofoam cover was in place (t = 0 s). Starting from t = 0 s to t = 1800 s, the temperature (T) was read-out at 5-minute intervals. Simultaneously, a digital heat-imaging camera (SP Thermoview 3800, Sensor Partners) was used to take heat images from the top, bottom and sides of the shoe. This experiment was repeated 3 times with every shoe. The shoe was allowed to return to room temperature in-between experiments.

3. Experimental test results

The test results are presented below (figure 2). Figure 2 shows that the water in shoe 4 cools down the fastest and shoe 5 the slowest. The faster the water inside the shoe cools down the better the shoe dissipates heat. The temperature of the room was constant at 21.6 °C. The boxplot show the highest and lowest measured values. The line shows the average of the measurements.

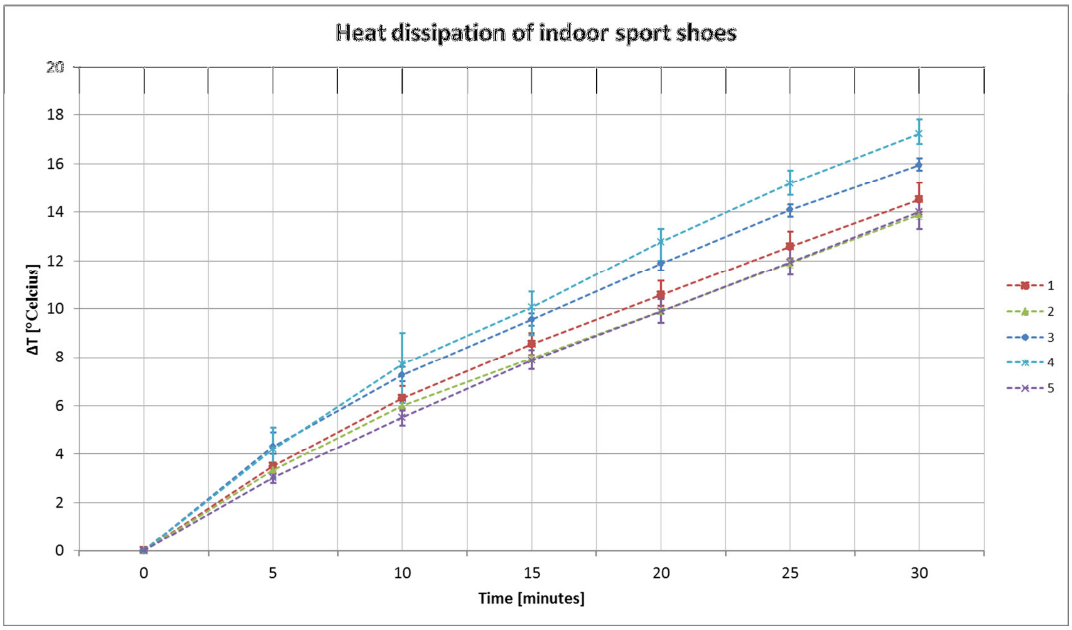

Figure 2 Experimental results: temperature difference over time. Plotted lines connect the average values over three tests.

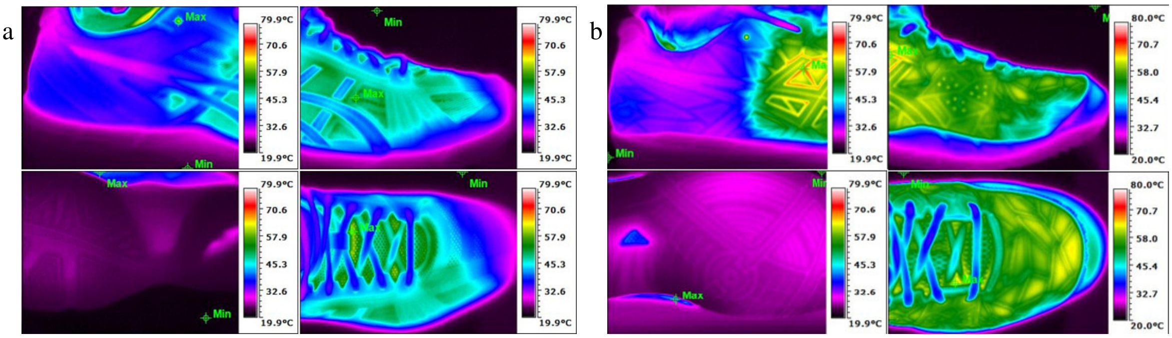

Figure 3. (a) Heat Image of shoe 1; (b) Heat image of shoe 2

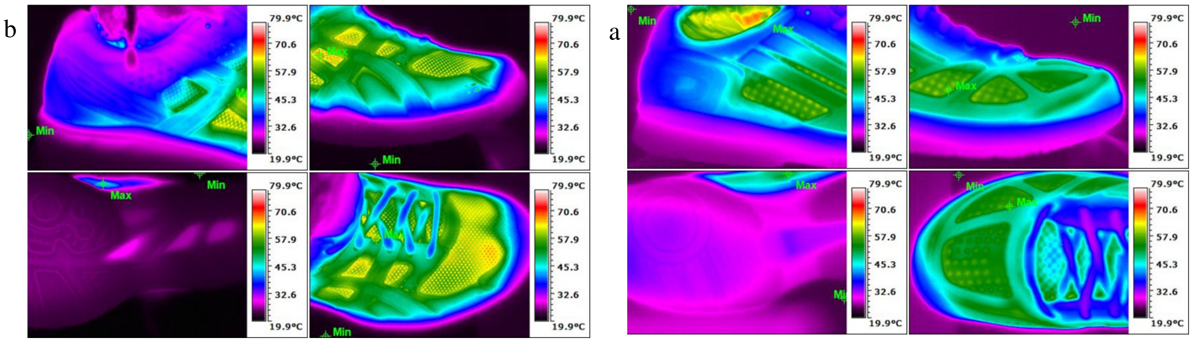

Figure 4. (a) Heat image of shoe 3; (b) Heat image of shoe 4

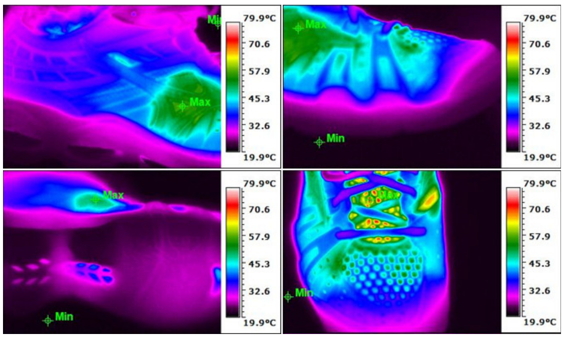

Figure 5. Heat image of shoe 5

4. Discussion and Conclusion

The experiment shows that shoe 4 dissipates heat best and shoe 5 dissipates heat worst. Shoe 1, 2, 3 perform in-between. From the heat images we can conclude that the brand logo and the part supporting the heel show the lowest heat transfer rates. The sole of the shoe was the worst heat conductor of all shoes tested. This can be concluded from the darker colours in the heat images (Maldaque et al., 2001).

From the images made, it can be seen that the mesh is lighter than the surrounding material. This means it is around 10 – 15 degrees warmer. The mesh in shoe 1 had a lower temperature than the mesh in shoe 3. A reason for this is that there might be plastic layers inside the mesh of shoe 1 blocking the airflow and therefore ventilation. Shoe 5 also had mesh but this mesh was significantly thicker than the other shoes; this might allow for less ventilation. Shoe 4 used EVA foam with large holes instead of mesh; from the heat image EVA foam appears to allow more ventilation.

Laces can block airflow and light up 'cold' on all heat images. A reason for this is that the laces are positioned more on top of the shoe. The sole of the shoe is the coldest area of the shoe. The ventilation holes in the sole of Shoe 2 and 5 work but ventilate little heat in comparison to the upper part of the shoe (fig. 3-5). The surface area of these holes was very small compared to the rest of the sole. The holes in the sole of shoe 5 have a surface area of around 5 cm^2. The holes in shoe 2 have a surface area of around 1.5 cm^2.

Shoe 1, 2, 3 and 5 contain isolating material behind the mesh or ventilation holes, especially in the heel of the shoe. This makes the shoes isolate more this can be seen in the heat images.

It is clear that the temperature range used for testing was not representative for temperatures under normal use. During preliminary tests with the same camera at normal foot temperatures, the differences in heat dissipation from specific areas of the shoe were hard to distinguish. Therefore, a higher temperature was used. Also, water cools down faster from a higher temperature, making the differences between shoes more clear. Insulation values are dependent of thermal conductivity, surface emission, insulation thickness, insulation density and specific heat capacity. These are all material properties and not dependent of temperature. A higher temperature only amplifies the results. Hence, the test was valuable to show the design strengths and weaknesses of the shoes tested.

The process of making the thermal image took 1 minute. An improved set up would consist of a camera for every angle on a tripod making pictures at the same time from exactly the same distance. The Styrofoam did not close every shoe completely because every shoe opening was slightly different. Another important factor is that this test is done in a stationary setup. The shoes from a real volleyball player are rarely stationary.

5. Recommendations

As the shoes from a volleyball or handball player are never stationary, it was useful to do the same tests with airflow around the shoe created by ventilators. This principle is called forced convection, which makes shoes cool down faster (Mills, 1999). Also the same test with a more realistic heat source around body temperature could be useful.

The heat images show that the sole of each tested shoe is the most isolating part of each shoe; it is probably the best area to start improving. Also the heel part is an isolating part of a shoe. The problem with the heel and the sole is that these parts of the shoe are very important for comfort and stability: this makes them difficult to improve without affecting the other properties of the shoe. Looking at advantages of every shoe and combining them could be used for further research.

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